DIGITAL VS SAW MATCHED FILTER IMPLEMENTATION FOR RADAR PULSE COMPRESSION

P.Tortoli, F.Guidi and C.Atzeni

Electronic Engineering Department, University of Florence,
via S.Marta 3, 50139 Florence, Italy

Abstract - The implementation of a *full-digital* system for radar pulse compression is described. The use of a high-speed FFT processor allows the matched filter to operate in the frequency domain at a throughput rate of some MHz. FM signals having time-bandwidth products up to 512 can be processed.
By using the sophisticated procedures developed for chirp waveform design in SAW filter implementations, the system is shown capable of providing compressed pulses with sidelobe levels in the 60 dB range. Significant experimental results are reported, and compared with those yielded by equivalent SAW compressors.

INTRODUCTION

Radar pulse compression systems have so far used Surface Acoustic Wave (SAW) devices for both transmission and matched filtering of Frequency Modulated (FM) waveforms[1]. In the last few years, digital solutions have been widely employed for generation of signals to be transmitted, while few alternatives to the SAW matched filter (compressor) have appeared in open literature. In fact, even if increasing demands of programmability and reproducibility strongly drive to this direction, the large number of high-speed multiplications and accumulations involved in compressor operation, creates serious difficulties in the implementation of a digital Finite Impulse Response filter.
It is known that a possible alternative is represented by frequency domain operation[2], consisting of multiplication between the Fourier Transform of the received FM echo signal and the Fourier Transform of a matched waveform. Dedicated architectures based on this approach have so far needed a large number of Printed Circuit Boards (PCB's), to reach the processing speed of SAW devices. However, the power consumption often came out to be in the range of hundreds of Watts, an order of magnitude larger than the power usually needed for SAW-based modules.

Thanks to recent technological developments, it has been possible to implement a digital system which can finally represent a suitable low-cost alternative to analog matched filter implementations. In this paper we describe a prototype digital compressor, using advanced but commercially available components which have been housed in a single PCB. The system, which is fully programmable, is shown capable to provide compressed pulses with sidelobe levels very close to the theoretical values. Its speed is adequate for processing of waveforms with long duration and moderate bandwidth, at the expenses of a power consumption of approximately 10 Watts.

SYSTEM ARCHITECTURE

A block diagram of the experimental digital compressor is shown in Fig.1. It basically consists of I/O FIFO memories, two identical processors for direct and inverse Fast Fourier Transform (FFT), and a high-speed complex multiplier for fast convolution in the frequency domain. The compressor complex spectrum, stored in fast EPROMS, is computed through a CAD program which has been developed for the design of a large class of linear and non-linear FM waveforms.

1051-0117/94/0000-0199 $4.00 © 1994 IEEE

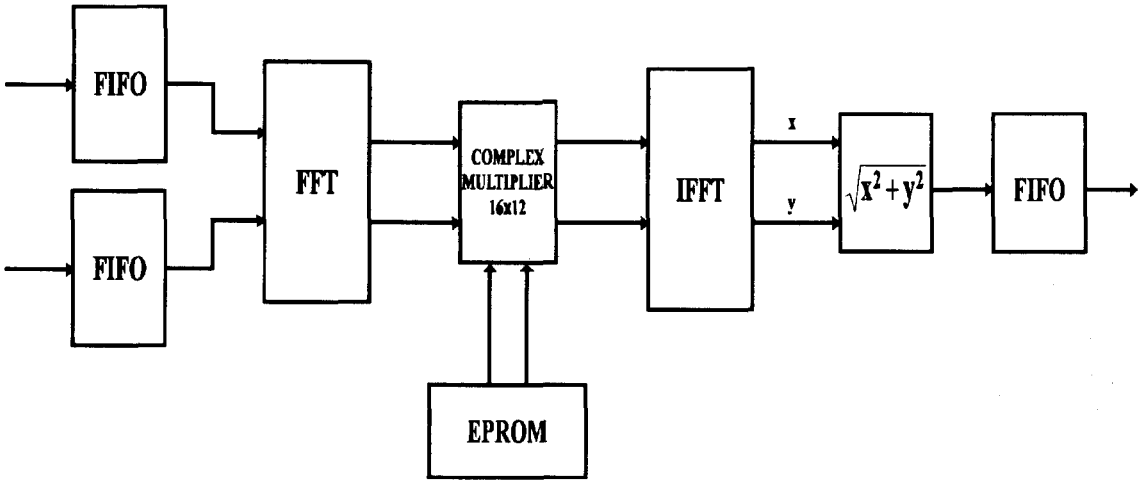

Fig.1: Block diagram of the digital matched filter operating in the frequency domain.

The heart of the system is represented by an ultra-fast FFT processor, the PDSP16515[1], which has here been used to implement 256 and 1024-point radix-4 FFT in about 22 μs and 110 μs, respectively. For 256-point FFT, the processor simultaneously allows new data to be loaded, present data to be transformed, and previous results to be dumped. The full system can operate in a similar pipeline fashion, by overlapping operations such as data acquisition, direct FFT, complex multiplication by the reference spectrum, inverse FFT and dumping output data. The corresponding I/O data rate, being conditioned by the slower of these operations, turns out to be about 8 MHz. On the other hand, for 1024-point FFT, the processor cannot accept new data before dumping out previous results. Hence, the maximum allowed I/O data rate is here limited to about 3 MHz.
The above throughput rates can be simply related to the Time-Bandwidth product (BT) of the FM waveform to be processed. Since the system operation is performed in blocks of N-points (N being equal to the FFT dimension) and possible time domain overlaps due to the inherent circular convolution have to be avoided, the maximum signal duration is given by $T = \frac{1}{2} N/F_S$ (F_S being the input signal sampling rate). On the other hand, according to Nyquist criterion, acquisition of a chirp signal at a rate F_S yields a maximum bandwidth (including both positive and negative frequency components) $B = F_S$. Hence, according to Tab.I, the maximum BT products corresponding to 256 and 1024-point FFT are equal to 128 and 512, respectively.

[1]Manufactured by GEC Plessey Semiconductor, UK.

N. of FFT points	Throughput rate (Fs)	Pulse Length (Tmax)	Max BT product
256	8 MHz	512/Fs	128
1024	3 MHz	128/Fs	512

Tab.I: Performance obtainable with the experimental digital pulse compression module (B is here assumed to be equal to F_S).

Of course, a reasonable oversampling margin, wide enough to avoid possible overlap between adjacent spectral images, is usually recommended. When, for continuous system operation, typical processing methods such as the overlap and save method[3], are employed, the throughput rate is furtherly scaled down.

EXPERIMENTAL RESULTS

Chirp waveform design must here observe the same criteria followed in SAW compression loop implementations. In both cases, an upper limit is imposed on the waveform length: in the digital approach, this limit is related to the number of FFT points, while in SAW implementations it is connected to the physical dimension of available piezoelectric substrates. As usual, the problem of sidelobe reduction has been faced in terms of compressor weighting and reciprocal ripple design. Non linear chirp waveforms, in particular, have been designed according to more sophisticated CAD tools which also take into account the need of maintaining insertion loss at minimal levels.

As known, the actual performance of SAW chirp filters is strongly conditioned by the so-called 2nd order effects, mainly originated by technological limits in device fabrication and by Mass Electrical Loading (MEL), bulk wave propagation and diffraction effects. In a digital approach, performance can be affected by quantization and truncation of data and coefficients. In our implementation, we have choosen a 12-bit resolution for input and compressor spectral data, while in the FFT processor data and coefficients are each represented by 16 bit, with block floating point arithmetic for increased dynamic range. The output compressed pulse amplitude is also represented with 16 bit. As shown below, these formats allow to maintain deviations from ideal behaviour at minimum levels.

The digital matched filter has been inserted in a compression loop which includes digital expander circuits providing 12-bit in-phase and quadrature components of the chirp signal to be transmitted. The system is fully programmable: for each chosen FM radar pulse, the related expander waveform and compressor spectrum are stored in corresponding EPROMS.

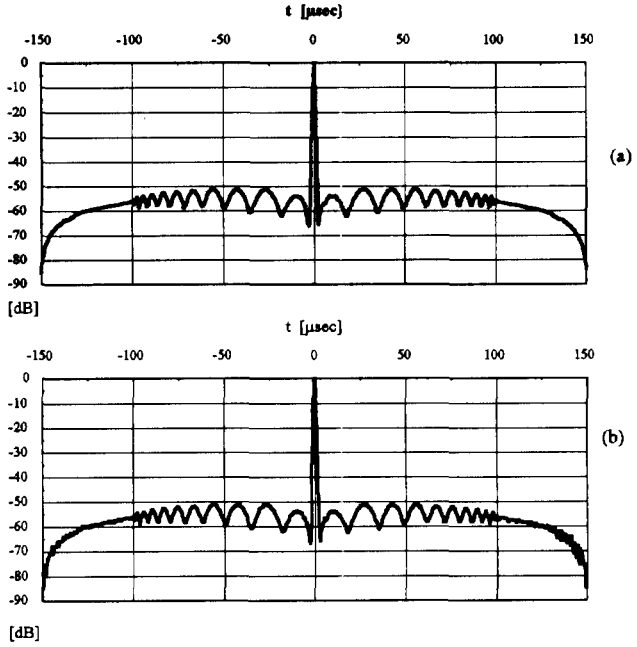

Fig.2: Ideal (a) and experimental (b) compressed pulses obtained for 2.1 MHz bandwidth and 150 μs duration nonlinear chirp.

The system has been tested with a number of waveforms designed within the limits specified in Tab.I. In all cases, differences between ideal and experimental compressed pulses have been maintained lower than 2 dB. Fig.2a shows the ideal compressed pulse, obtained from a non-linear FM waveform designed on the basis of a 30 dB truncated Gaussian function with 2.1 MHz bandwidth and 150 μs duration. The corresponding experimental compressed pulse, shown in Fig.2b, was obtained with 3 MHz I/O data rate and 1024 point FFT. This result is nearly identical to the ideal one, since only slight differences at very low signal levels can be observed.

Fig.3 reports an example of -60 dB compressed pulse obtained by sampling at 4.2 MHz a chirp waveform having a 22 Time Bandwidth product. To limit the amplitude of gating sidelobes, the compressor was here made approximately two times longer than the expander, and Reciprocal Ripple Design (RRD) was employed (see Fig.3a).

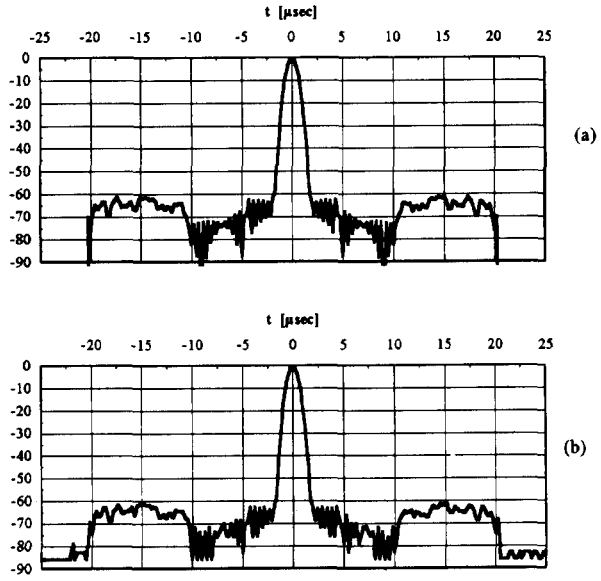

Fig.3: Ideal (a) and experimental (b) compressed pulse obtained for 2.2 MHz bandwidth and 10 μs duration nonlinear chirp.

The digital compressed pulse (Fig.3b) exhibits an almost ideal behaviour, with slight deviations at sidelobe levels around -60 dB, which can be attributed to the fixed point arithmetic employed in the FFT processor.
SAW filters designed according to the same criteria used in the digital approach, typically yield larger sidelobes. A significant example is shown in Fig.4, obtained by using

a state-of-the-art SAW filter[2] operating in the VHF range. The larger sidelobes visible after the compressed pulse can be here attributed to MEL, which was only partially corrected because this result was already within the system design requirements. However, it can be observed that even in the first time interval, where MEL does not produce significant effects, the sidelobe level is in the 50dB range, which for SAW devices must be considered an excellent result.

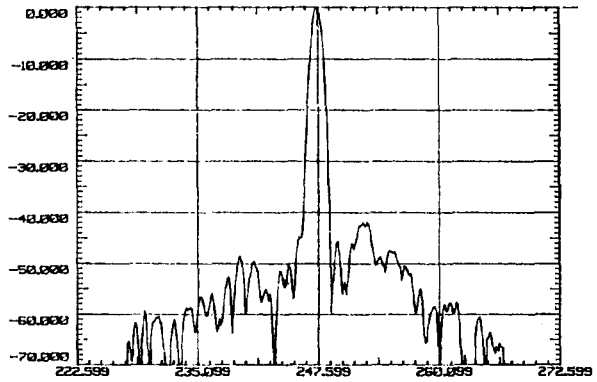

Fig.4: Compressed pulse obtained by a SAW compressor designed according to the same criteria used for the digital pulse shown in Fig.3.

CONCLUSION AND DISCUSSION

Full-digital implementations of the matched filter needed for radar pulse compression have been so far limited to equipments characterized by extremely high cost and power consumption. In this paper we have described the implementation of a digital compressor consisting of commercial devices housed in a single PCB, clocked at 36 MHz, consuming about 2 A at 5 Volts. The board is suitable for compression of chirp waveforms having bandwidths in the range of some MHz, with BT products which can vary from a few tens to several hundreds.
Compared to analog implementations, the system offers the advantage to be fully programmable and to guarantee almost ideal performance for any chirp signal. In order to obtain sidelobe levels in the 60 dB range, in fact, SAW chirp filters need to be cascaded with custom made SAW equalizers[4], and a very sophisticated technology is involved.

[2]Manufactured By Micrel SpA, Florence, Italy.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the valuable assistance of M.Baldanzi and G.Marrone in the system implementation. They also like to thank J.Mather and L.Wyatt, by GEC Plessey Semiconductor, for their considerable help in the evaluation of FFT processor performance, and L.Frangini and D.Cioppi, by Micrel SpA, for providing experimental results and useful information on SAW implementation.

REFERENCES

[1] M.B.N. Butler, "Radar Applications of SAW Dispersive Filters", IEE Proc. F, Commun., Radar & Signal process., 1980, 127, (2) pp. 118-124.

[2] E.E. Swartzlander and G. Hallnor , "Frequency Domain Digital Filtering with VLSI", in Kung, S.Y. , Whitehouse, H.J. and Kailath T. (Eds.): 'VLSI and modern signal processing' (Prentice Hall, Englewood Cliffs, NJ, 1985), Chap.19.

[3] L.R. Rabiner, B. Gold, "Theory and Applications of Digital Signal Processing", Prentice Hall, 1975.

[4] P. Dubouis, J.P. Gragnolati, E. Psaila, M. Solal, "A -60Db sidelobe Pulse Compression System for Space Application", in 1992 IEEE Ultrason. Symp. Proc., pp.231-235.